Claims

1. A method for estimating the occurrence of a specific tire pressure deviation between actual and nominal pressure values for one or a plurality of wheels (i), comprising the following steps:
   a) subsequently obtaining one or more wheel radius analysis measurement values (ΔR) from a wheel radius analysis component (104), wherein the wheel radius analysis measurement values (ΔR) are related to single wheel radius values (Δr_i) of which each is indicative of the wheel radius of a particular wheel (i);
   b) subsequently obtaining one or more wheel vibration data values (Δf_i) from a wheel vibration analysis component (102), wherein each of the wheel vibration data values (Δf_i) is indicative of a vibration phenomena in the time dependent behavior of the rotational velocity of a particular wheel (i); and
   c) calculating one or more tire pressure output values (η_i, Δp_i) on the basis of both the wheel radius analysis measurement values (ΔR) and the wheel vibration data values (Δf_i) wherein each tire pressure output value (η_i, Δp_i) is indicative of the specific tire pressure deviation for a particular wheel (i)

2. The method of claim 1, wherein the calculation of the tire pressure output value (η_i) for each wheel (i) comprises the following:
   - calculating a first probability value (P_i^f) from the wheel vibration data value (Δf_i) which is indicative of the statistical significance of the deviation of the wheel vibration data value (Δf_i) from a nominal wheel vibration value;
   - calculating a second probability value (P_i^r) from the wheel radius analysis measurement values (ΔR) which

is indicative of the statistical significance of the deviation of the single wheel radius values (Δr_i) from a nominal wheel radius value; and

- calculating the tire pressure output value (η_i) from the first and second probability values (P_i^f, P_i^r).

3. The method of claim 2, wherein the first and second probability values (P_i^f, P_i^r) are cumulative probability distribution function values; and the tire pressure output value (η_i) is based on the product of the first and second cumulative probability distribution function values (P_i^f, P_i^r).

4. The method of claim 3, wherein the first and second cumulative probability distribution function values (P_i^f, P_i^r) are Gaussian cumulative probability distribution function values; and the calculation of the first and second probability values (P_i^f, P_i^r) is further based on a first and a second standard deviation parameter (σ_f, σ_r), respectively.

5. The method of claim 3 or 4, wherein the product of the first and second cumulative probability distribution function value (P_i^f, P_i^r) is further multiplied with a weight factor (W_i^{fr}), which is calculated on the basis of the wheel vibration data value (Δf_i), the wheel radius analysis measurement values (ΔR) or the single wheel radius values (Δr_i), and of standard deviation parameters (σ_f, σ_r).

6. The method of claim 5, wherein the weight factor W_i^{fr} is calculated as follows:

$$W_i^{fr} = \exp\left(\sigma_1 \left|\frac{\Delta f_i}{\sigma_f} - \frac{\Delta r_i}{\sigma_r}\right|\right) \cdot \exp\left(\sigma_2 \left|\frac{\Delta f_i \Delta r_i}{\sigma_f \sigma_r}\right|\right),$$

wherein Δf_i is the wheel vibration data value, Δr_i is the single wheel radius value, σ_f and σ_r are standard deviation parameters, and σ_1 and σ_2 are tuning parameters.

7. The method of claim 5, wherein the weight factor W_i^{fr} is calculated as follows:

$$W_i^{fr} = \exp\left(\sigma\left|\frac{\Delta f_i \Delta r_i}{\sigma_f \sigma_r}\right|\right),$$

wherein Δf_i is the wheel vibration data value, Δr_i is the single wheel radius value, σ_f and σ_r are standard deviation parameters, and σ is a tuning parameters.

8. The method of claim 1, wherein the calculation of the tire pressure output value (Δp_i) is based on a model assuming a linear relationship between on the one hand the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) and on the other hand the tire pressure output value (Δp_i).

9. The method of claim 8, wherein the tire pressure output value (Δp_i) is calculated from the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) by a Least Mean Square method (516).

10. The method of claim 8, wherein the pressure deviation value (Δp_i) is calculated from the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) by an adaptive filter (716).

11. The method of claim 10, wherein the adaptive filter (716) is a Kalman filter.

12. The method of any of the preceding claims, wherein the wheel radius analysis measurement values (ΔR) are transformed to modified wheel radius values ($\Delta\tilde{R}$) which are less sensitive to load changes on the plurality of wheels (i).

13. The method of any of the preceding claims, which comprises the following steps:
- calculating a load balance value (l) on the basis of the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) which is indicative of a load balance on the plurality of wheels (i);
- calculating load balance corrected wheel radius analysis measurement values ($\Delta\tilde{R}$) on the basis of the wheel radius analysis measurement values (ΔR) and the estimated load balance value (l).

14. The method of claim 13, wherein the calculation of the load balance value (l) is based on a model assuming a linear relationship between on the one hand the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) and on the other hand the tire pressure output values (Δp_i) and the load balance value (l).

15. The method of claim 14, wherein the load balance value (l) is calculated from the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) by a Least Mean Square method (1014).

16. The method of claim 14, wherein the load balance value (l) is calculated from the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) by an adaptive filter (1014).

17. The method of claim 16, wherein the adaptive filter (1014) is a Kalman filter.

18. The method of claim 1, which comprises the following steps:
   - collecting data value pairs consisting of a single wheel radius data value (Δr_i) and a wheel vibration data value (Δf_i) during test drives,
   - defining an area which comprises the collected data value pairs, and
   - calculating the tire pressure output value by testing whether an actual data value pair obtained during normal drives lies within the defined area or not.

19. The method of claim 1, wherein the tire pressure output value is calculated on the basis of a χ^2-test from the single wheel radius data values (Δr_i) and the wheel vibration data values (Δf_i).

20. The method of claim 1, wherein the calculation of the tire pressure output value (Δp_i) is based on a model assuming a linear relationship between on the one hand the wheel vibration data and the wheel radius analysis measurement values (Δf_i, ΔR) and on the other hand the tire pressure output value (Δp_i) and a load balance value (l), wherein the load balance value (l) is treated as a random variable and the tire pressure output value (Δp_i) is calculated by a Least Square method from the model.

21. The method of claim 1, wherein the calculation of the tire pressure output value (Δp_i) is based on a specific function relating the tire pressure output value (Δp_i) with the wheel vibration data values (Δf_i), the wheel radius analysis measurement values (ΔR) and further parameters, wherein the further parameters are determined during test drives by a Least Square method on the basis of the specific function, obtained tire pressure output values (Δp_i), obtained wheel vibration data values (Δf_i) and corresponding tire pressure values.

22. The method of claim 21, wherein the specific function is a series expansion in the wheel vibration data values (Δf_i) and the wheel radius analysis measurement values (ΔR).

23. The method of claim 21, wherein the series expansion is established by a neural network or a radial basis function network.

24. The method of any of the preceding claims, wherein each of the wheel radius analysis measurement values either corresponds to a single wheel radius value or to a linear combination of single wheel radius values.

25. The method of any of the preceding claims, wherein the vibration phenomena comprises spectral properties in the time dependent behavior of the rotational velocity of a particular wheel (i).

26. A system for estimating the occurrence of a specific tire pressure deviation between actual and nominal pressure values for one or a plurality of wheels (i), comprising:
   a) a first component for subsequently obtaining one or more wheel radius analysis measurement values (ΔR) from a wheel radius analysis component (104), wherein the wheel radius analysis measurement values (ΔR) are related to single wheel radius values (Δr_i) of which each is indicative of the wheel radius of a particular wheel (i);
   b) a second component for subsequently obtaining one or more wheel vibration data values (Δf_i) from a wheel vibration analysis component (102), wherein each of the wheel vibration data values (Δf_i) is indicative of a vibration phenomena in the time dependent behavior of the rotational velocity of a particular wheel (i); and
   c) a third component for calculating one or more tire pressure output values (η_i, Δp_i) on the basis of both

the wheel radius analysis measurement values (ΔR) and the wheel vibration data values (Δf_i) wherein each tire pressure output value (η_i, Δp_i) is indicative of the specific tire pressure deviation for a particular wheel (i)

27. A computer program product including program code for carrying out a digital signal processing method, when executed on a computer system, for estimating the occurrence of a specific tire pressure deviation between actual and nominal pressure values for one or a plurality of wheels (i), comprising the following steps:
    a) subsequently obtaining one or more wheel radius analysis measurement values (ΔR) from a wheel radius analysis component (104), wherein the wheel radius analysis measurement values (ΔR) are related to single wheel radius values (Δr_i) of which each is indicative of the wheel radius of a particular wheel (i);
    b) subsequently obtaining one or more wheel vibration data values (Δf_i) from a wheel vibration analysis component (102), wherein each of the wheel vibration data values (Δf_i) is indicative of a vibration phenomena in the time dependent behavior of the rotational velocity of a particular wheel (i); and
    c) calculating one or more tire pressure output values (η_i, Δp_i) on the basis of both the wheel radius analysis measurement values (ΔR) and the wheel vibration data values (Δf_i) wherein each tire pressure output value (η_i, Δp_i) is indicative of the specific tire pressure deviation for a particular wheel (i)